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B1S
H1K
Selected US specifications from IPC sub-class C30B

(54) Oxygen containing silicon substrates

(57) A method for producing silicon substrates includes growing the silicon crystal body at a relatively high rate of growth. It has been found that the growth rate of the silicon crystal body exerts substantial influence upon generation of crystal defects in the silicon crystal body or silicon substrate. Furthermore, the oxygen concentration in the silicon crystal body or the silicon substrate is significantly higher than in conventional silicon crystals or substrates. The high growth rate of the silicon crystal body suppresses separation of the oxygen from the crystal body. This reduces the number of defects or faults formed in the crystal body during heat treatment during production of the semiconductor devices. In the preferred process, according to the present invention, the growth rate of the silicon crystal body is greater than or equal to 1.2 mm/min. Furthermore, the preferred oxygen concentration in the grown silicon crystal body is selected to be greater than or equal to $1.8 \times 10^{18} cm^{-3}$.

FIG. 1

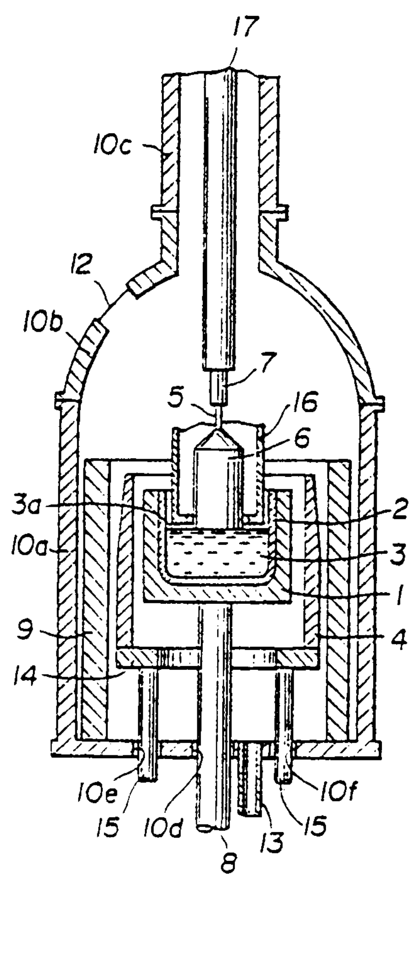


FIG. 1

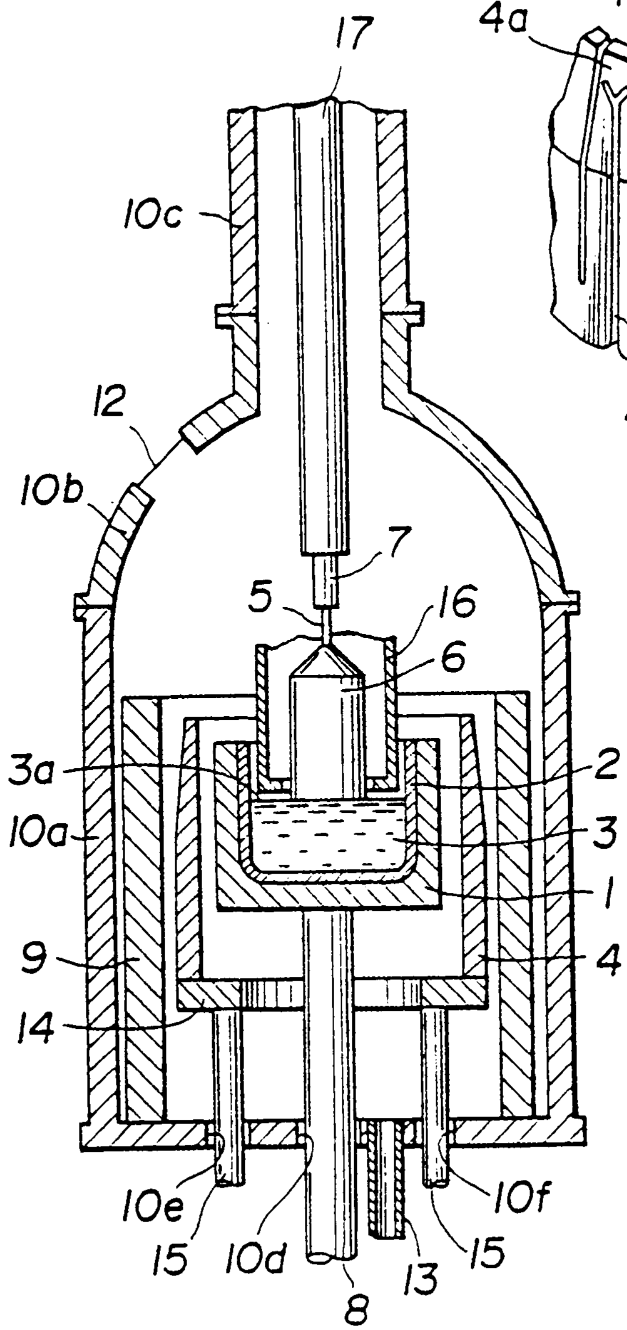

17
10c
12
10b
7
5
16
6
3a
2
10a
3
1
9
4
14
10e
10f
15
10d
13
15
8

FIG. 2

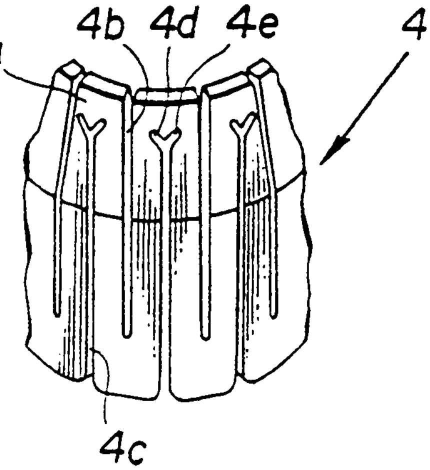

4b
4d
4e
4
4a
4c

FIG. 3

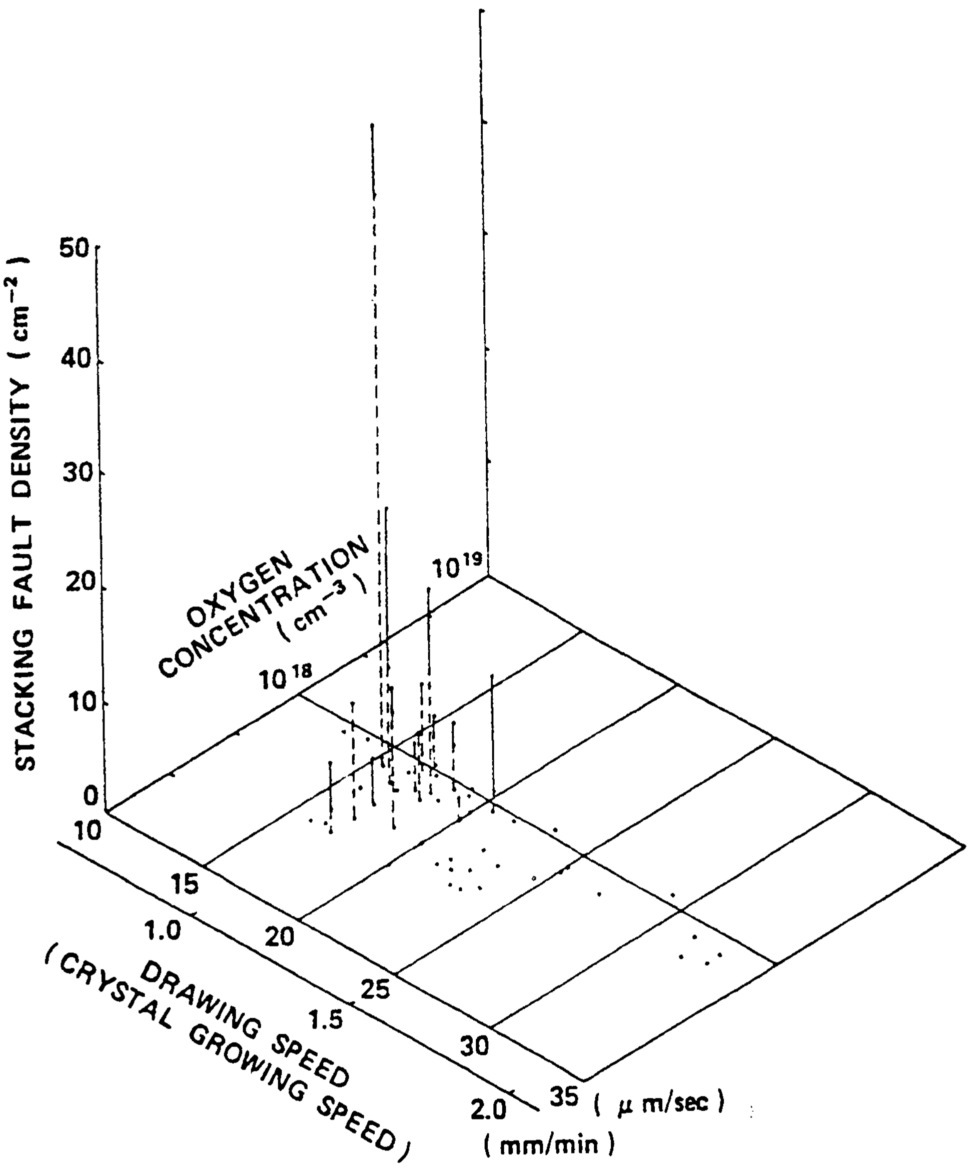

STACKING FAULT DENSITY (cm^{-2})
50
40
30
20
10
0
OXYGEN CONCENTRATION (cm^{-3})
10^{18}
10^{19}
10
15
20
25
30
35 (μ m/sec)
1.0
1.5
2.0
(mm/min)
DRAWING SPEED
(CRYSTAL GROWING SPEED)

FIG.4

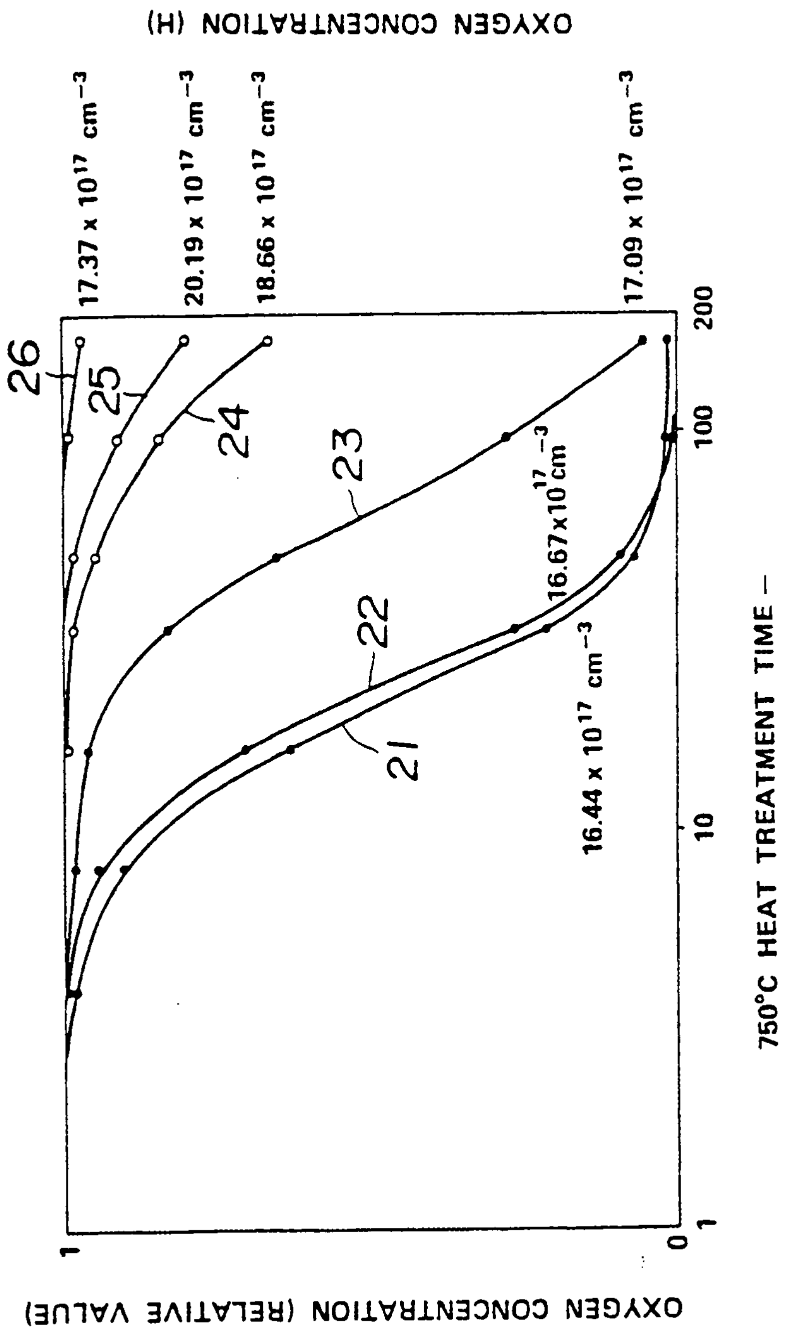

OXYGEN CONCENTRATION (H)
17.37 x 10^{17} cm^{-3}
20.19 x 10^{17} cm^{-3}
18.66 x 10^{17} cm^{-3}
17.09 x 10^{17} cm^{-3}
16.67x10^{17} cm^{-3}
16.44 x 10^{17} cm^{-3}
26
25
24
23
22
21
1
10
100
200
0
1
750°C HEAT TREATMENT TIME –
OXYGEN CONCENTRATION (RELATIVE VALUE)

FIG.5

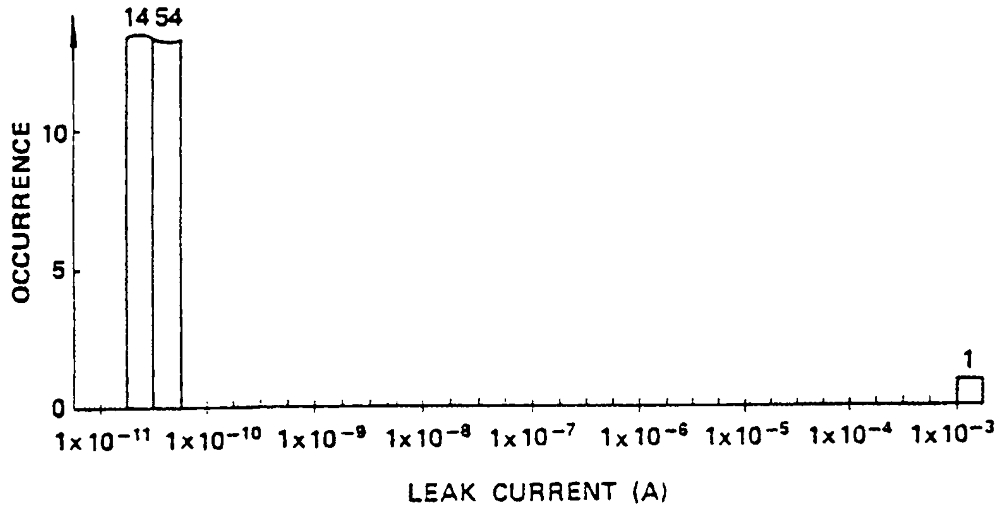

1454
1
OCCURRENCE
10
5
0
1x10⁻¹¹ 1x10⁻¹⁰ 1x10⁻⁹ 1x10⁻⁸ 1x10⁻⁷ 1x10⁻⁶ 1x10⁻⁵ 1x10⁻⁴ 1x10⁻³
LEAK CURRENT (A)

FIG.6

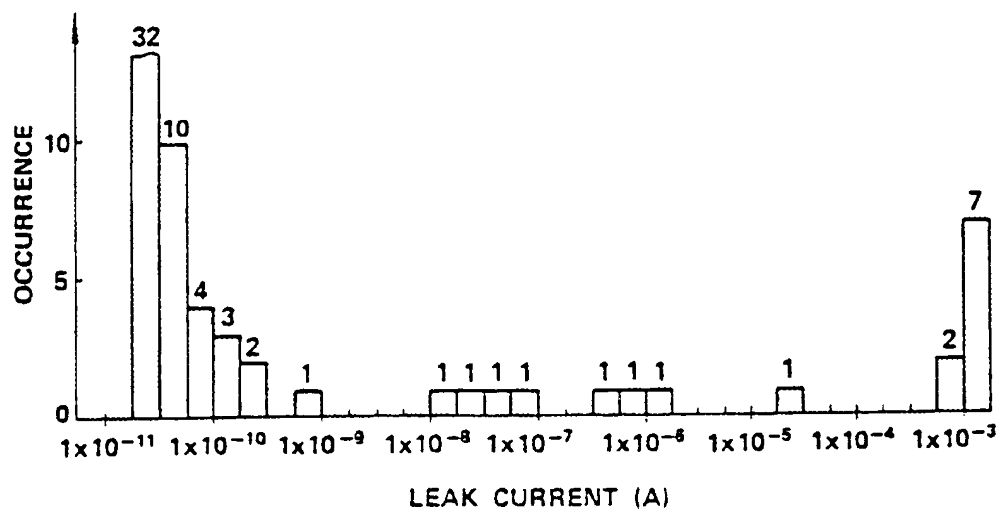
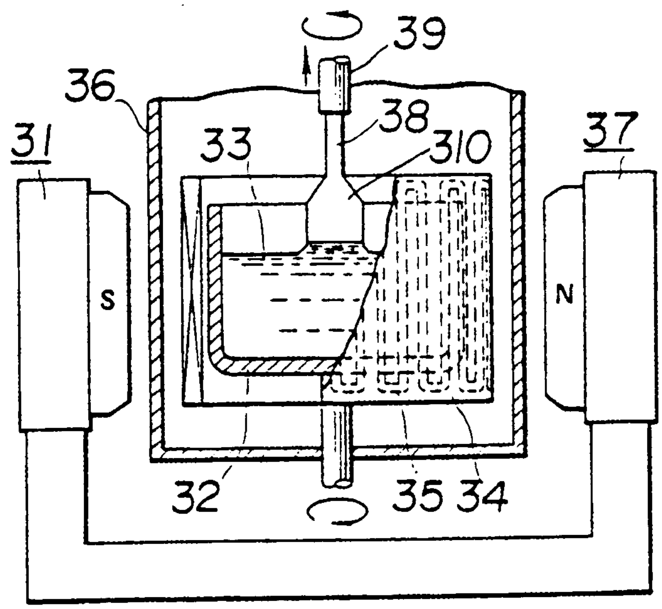

32
10
4
3
2
1
1 1 1 1
1 1 1
1
2
7
OCCURRENCE
10
5
0
1x10⁻¹¹ 1x10⁻¹⁰ 1x10⁻⁹ 1x10⁻⁸ 1x10⁻⁷ 1x10⁻⁶ 1x10⁻⁵ 1x10⁻⁴ 1x10⁻³
LEAK CURRENT (A)

FIG. 7



SPECIFICATION

High-oxygen-content silicon monocrystal substrate for semiconductor devices and production method therefor

BACKGROUND OF THE INVENTION

Field of the invention

The present invention relates generally to a silicon monocrystal substrate capable of absorbing significant metal contamination. In addition, the invention relates to a method for producing a silicon crystal substrate with a significant oxygen concentration. In particular, the invention relates to a method and device for producing a high-oxygen-concentration silicon substrate by way of crystal growth.

Description of the background art

Silicon substrates are widely used for producing various semiconductor devices. In such semiconductor devices, it is generally preferable to minimize leak current. It is known that the leak current can be lowered by an effect called intrinsic gettering (I.G.). The I.G. effect can be achieved as a result of defects formed in the internal structure of the silicon substrate.

As is well known, a silicon substrate is derived from a silicon crystal body prepared by growing a silicon monocrystal from molten polycrystalline silicon by the Czochralski method (hereafter referred to as the "CZ method"), for instance. In the CZ method, the monocrystal silicon body is drawn slowly out of a bath of molten polycrystal silicon. Silicon substrates are obtained by sectioning or "wafering" the finished silicon monocrystal body.

The finished silicon crystal body contains a great amount of oxygen. The oxygen in the silicon crystal body generates defects or crystal dislocations such as dislocation loops, stacking faults and so forth due to oxygen segregation during heat treatment of the silicon substrate. The defects in the finished semiconductor device degrade its rated characteristics in particular, lower its break-down voltage, and increase its leak current. As a result, the production yield of semiconductor devices is significantly lowered.

On the other hand, it has been found that the defects in semiconductor devices may serve to absorb metal contaminants by the so-called intrinsic gettering or I.G. effect. For instance, in semiconductor devices in which the surface of the silicon substrate is the major active region, such as in insulated-gate field-effect transistors (MOS-FET's) or integrated circuits employing MOS-FET's, defects in the silicon substrate outside of the major active region exhibit the I.G. effect, absorbing metal contaminants from the active regions. This helps reduce the leakage current of the semiconductor devices.

However, there are difficulties in achieving a consistent I.G. effect in mass production. For instance, in cases where the silicon crystal body is grown by the conventional CZ method, the concentration of defects in the crystal body tends to be substantially different at the top, corresponding to the beginning of growth, than at the bottom, corresponding to the end of growth, due to thermal hysteresis. Furthermore, although a high oxygen concentration is preferable to enhance the I.G. effect, when the oxygen concentration is excessively high, defects tend to form even at the surfaces of the semiconductor devices, resulting in deterioration of the characteristics of the semiconductor devices as set forth above. In addition, in some semiconductor production processes, attention must be paid to precise control of the oxygen concentration or special I.G. treatments must be performed in view of the heat-treatment conditions required for production of some semiconductor devices.

Thus, it is a continuing problem in the art of efficiently manufacturing silicon substrates for semiconductor devices to obtain a substantially high concentration of oxygen, sufficient to enhance the I.G. effect to lower leak current without generating an adverse effect for defects in the finished semiconductor device, especially after heat treatment.

Summary of the invention

Therefore, it is a general object of the invention to provide a silicon substrate and production method therefor, which can resolve the problems set forth above.

Another object of the invention is to provide a silicon substrate containing a relatively high concentration of oxygen without deterioration of its characteristics due to oxygen segregation, dislocation loops, stacking faults and so forth.

A further object of the present invention is to provide a method for producing silicon substrates as a starting material for production of semiconductor devices, which allows high yield without causing deterioration of the characteristics of the finished products.

In order to accomplish the above-mentioned and other objects, a method for producing silicon substrates includes growing the silicon crystal body at a speed higher than is conventionally used. It has been found that the growth rate of the silicon crystal body exerts a significant influence on generation of defects in the silicon crystal body. Furthermore, according to the present invention, the oxygen concentration in the silicon crystal body or the silicon substrate is significantly higher than in the conventional silicon crystal bodies or substrates. Accelerating the growth of the silicon crystal body significantly suppresses separation of the oxygen in the crystal body. This reduces the number of defects or dislocations formed in the crystal body during heat treatment during production of the semiconductor devices.

In the preferred process, according to the present invention, the growth rate of the silicon crystal body is greater than or equal to 1.2 mm/min. Furthermore, the preferred oxygen concentration in the grown silicon crystal body is greater than or equal to $1.8 \times 10^{18} cm^{-3}$.

According to the invention, a silicon substrate containing oxygen in concentrations greater than or equal to $18 \times 10^{18} cm^{-3}$ can achieve a leak current less than or equal to 1×10^{-10}.

According to one aspect of the invention, a method of producing a silicon substrate containing a substantially high concentration of oxygen for semiconductor devices comprises the steps of:

growing a silicon monocrystal from a silicon melt at a substantially high rate of growth selected to prevent loss of oxygen from the monocrystal during subsequent heat treatment during production of the semiconductor device, and forming the silicon substrate from the silicon monocrystal.

The preferred growth rate of the silicon monocrystal is greater than or equal to 1.2 mm/min. On the other hand, the preferred oxygen concentration in the silicon substrate is greater than or equal to $1.8 \times 10^{18} cm^{-3}$. Further preferably, the growth rate of the silicon monocrystal is preferably in the range of approximately 1.5 mm/min. to 2.1 mm/min.

In the preferred embodiment, the silicon monocrystal growth step comprises the steps of: placing silicon in a crucible; heating the silicon so as to maintain the silicon in a fluid state; and gradually drawing the silicon monocrystal out of the silicon melt in the crucible.

In the step of the silicon, the heat applied thereto is sufficient to prevent the surface of the silicon from solidifying. More preferably, in the step of heating the silicon, more heat is applied to the surface of the silicon than to the remainder of the silicon melt.

In an alternative embodiment, the method further comprises the step of applying a magnetic field to the silicon. Furthermore, the preferred method may further comprise the step of driving the crucible to rotate. The magnetic field applied and/or the rotation speed of the crucible can be controlled so as to adjust the oxygen concentration in the silicon substrate.

According to another aspect of the invention, an apparatus for growing a silicon monocrystal containing a substantially high concentration of oxygen as a source for silicon substrates for semiconductor devices, in order to implement the aforementioned production method for the silicon substrate, comprises a crucible for receiving a silicon, a heater means for heating the silicon so as to maintain the silicon in a fluid state; and a drawing means for drawing the silicon monocrystal from the silicon melt in the crucible at a substantially high rate so as to prevent loss of oxygen from the substrate during subsequent heat treatment in a process of fabricating the semiconductor devices. Preferably, the drawing rate of the silicon monocrystal is greater than or equal to 1.2 mm/min. In addition, the preferred oxygen concentration in the silicon substrate is greater than or equal to $1.8 \times 10^{18} cm^{-3}$. The heating means applies sufficient heat to prevent the surface of the silicon melt from solidifying. The heating means thus applies more heat to the surface of the silicon melt than to the remainder of the silicon melt.

The apparatus further comprises means for applying a magnetic field to the silicon melt. In addition, the apparatus may further comprise means for driving the crucible to rotate. The crucible driving means drives the crucible at a variable speed allowing adjustment of the oxygen concentration in the silicon substrate.

According to a further aspect of the invention, a semiconductor device is produced from a silicon substrate having an oxygen concentration greater than or equal to $1.8 \times 10^{18} cm^{-3}$ and having a leakage current value less than 1×10^{-10} A.

Brief description of the drawings

The present invention will be understood more fully from the detailed description given herebelow and from the accompanying drawings of the preferred embodiment of the invention, which, however, should not be taken to limit the invention to the specific embodiment but are for explanation and understanding only.

In the drawings:

Figure 1 is a cross-section through a silicon crystal growing apparatus implementing the preferred embodiment of the silicon crystal production method according to the invention;

Figure 2 is a perspective view of part of the heating element of Figure 1;

Figure 3 is a three-dimensional graph of the observed relationships among the crystal growth rate, the oxygen concentration and stacking fault density;

Figure 4 is a graph of heat treatment time versus oxygen concentration;

Figures 5 and *6* show the results of measurements of leak current of a number of sample diodes obtained by the silicon substrate production method according to the invention and by a conventionally known process respectively; and

Figure 7 is a cross-section through a modified embodiment of the silicon crystal growing apparatus implementing the preferred embodiment of the silicon crystal production process according to the invention.

Description of the preferred embodiment

Referring now the the drawings, Figure 1 shows a silicon monocrystal growing apparatus implementing the preferred embodiment of a silicon substrate producing method according to the present invention. As will be seen from Figure 1, the preferred embodiment of the silicon substrate producing method includes a process for growing a silicon monocrystal body as a starting material for silicon substrates. According to the preferred process, the silicon monocrystal is grown by the CZ method.

In the monocrystal growing apparatus of the present invention, silicon 3 in a quartz crucible 2 disposed within a graphite crucible 1 is melted. A graphite heat generator 4 and a heat-insulating material 9 surround the crucible 1. Additional plural cooling jackets 10a, 10b and 10c surround the insulating material 9. The cooling jacket 10b has a window 12 for allowing observation of the drawn monocrystal 6. An exhaust pipe 13 is provided in the floor of the cooling jacket 10b for exhausting inert gas serving as an atmosphere introduced into the jackets 10a, 10b and 10c from above. A shaft 8 fixed to the lower surface of the crucible 1 passes loosely through an aperture 10d in the floor of the cooling jacket 10a and is used to rotate and lift or lower the crucible 1. The lower edge of the heat generator 4 is fixed to a ring plate 14, which in turn is fixed to a pair of shafts 15 passing loosely through two apertures 10e and 10f in the floor of the cooling jacket 10a. The shafts 15 are used to lift or lower the heat generator 4. A molybdenum cylindrical heat shield 16 with an inner diameter slightly larger than an outer diameter of the monocrystal 6 is disposed above the liquid silicon 3 and around the monocrystal 6. Within the heat shield 16, a seed crystal 5 is held by a chuck 7 attached to the lower end of a draw shaft 17 so that a cylindrical monocrystal 6 may be grown from the seed crystal 5.

In the CZ method, the maximum monocrystal growth rate V_{max} can be expressed as follows, assuming that the solid-liquid interface between the monocrystal 6 and the liquid 3 is flat and no radial temperature gradient exists in the monocrystal 6:

$$V_{max} = \frac{k}{h \cdot \rho} \left(\frac{dT}{dX}\right)$$

where k denotes the thermal conductivity of the monocrystal 6, h denotes the heat of solidification, ρ denotes the density, and dT/dX denotes the temperature gradient in the solid phase of the monocrystal 6 at the solid-liquid interface. Specifically, X denotes distance along the longitudinal axis of the monocrystal 6. In the above expression, since k, h and ρ are inherent properties of the material, it is thus necessary to increase the temperature gradient dT/dX in order to increase or obtain a large maximum monocrystal growth rate V_{max}. In the above-mentioned CZ method, however, since the monocrystal 6 is heated by radiation from the surface of the liquid 3, the inner wall of the crucible 2, and the heat generator 4, the value of the temperature gradient dT/dX is inevitably limited, so that the growth rate has always been relatively small in practice.

As will be appreciated from the above discussion, the growth rate of the silicon monocrystal can be accelerated by reducing the heat applied to the molten silicon 3 by the heat generator 4 and thus lowering the temperature of the molten silicon. Although this has a direct proportional effect toward lowering the thermal gradient, by the Stefan-Boltzmann law, the heat radiated toward the monocrystal is reduced to a much greater extent, so that the net effect is an increase in the temperature gradient dT/dX. However, reducing the heat generated by the heat generator 4 in order to obtain a higher growth rate means that the surface of the molten silicon will tend to solidify since the surface of the molten silicon is cooled by exposure to the gaseous furnace atmosphere. This limits the extent to which the temperature of the molten silicon 3 can be lowered.

The heat generator 4 of the preferred silicon monocrystal growing apparatus is designed to apply enough heat to the surface of the molten silicon 3 to maintain the silicon in the liquid state. In particular, the heat generator 4 of the preferred construction is designed to apply more heat to the surface of the molten silicon than to the remaining body of molten silicon so as to allow the temperature of the molten silicon 3 to be minimized.

Figure 2 shows the structure of the heat generator 4. The heat generator 4 is made of a conductive material such as graphite, and is generally in the form of a cylindrical sleeve with a tapered portion 4a at its upper end. The heat generator 4 is formed with alternating upper grooves 4b and lower grooves 4c, each extending parallel to the vertical axis of the heat generator 4. This construction provides the cylindrical shell with a serpentine configuration suitable for use as an electrical heating element. In addition, the upper ends of the lower grooves 4c are angularly bifurcated to form two short grooves 4d and 4e extending at an angle of 45° with respect to the groove 4c. Current passes through each section defined by adjoining upper and lower grooves 4b and 4c and generates heat due to ohmic loss.

In order to grow the monocrystal 6 with the seed crystal 5 from the melted silicon material by means of the monocrystal growing apparatus constructed as described, the two crucibles 1 and 2 are rotated in a clockwise direction by the shaft 8 and the grown monocrystal 6 is rotated by the shaft 17 in a counterclockwise direction, for instance, or vice versa. At the same time, the draw shaft 17 is lifted gradually by means of a driving mechanism (not shown) to draw the monocrystal 6 out of the melt. Additionally, the two crucibles 1 and 2 are both raised gradually so that the surface of the liquid 3 can be kept at a predetermined position with respect to the heat generator 4.

The apparatus described above has the following advantages: the upper end 4a of the heat generator 4 is tapered and, in addition, the bifurcated grooves 4d and 4e are formed at the upper ends of the lower grooves 4c, and the cross-sectional area of the tapered portion 4a is smaller than the rest of the heat generator 4. In particular, the cross-sectional area near the bifurcated grooves 4d and 4e is quite small. Therefore, as current passes through the heat generator 4, the tapered portion 4a of the heat generator 4 is heated to a higher temperature than other portions of the heat generator 4. As a result, the difference in temperature between the melt 3a located vertically opposite the tapered portion 4a and at the inner wall of the crucible 2, and the maximum value within the body of the melt 3 is small.

Furthermore, since the tapered portion 4a increases the total electrical resistance of the heat generator 4 relative to conventional models, the temperature of the heat generator 4 will be higher, assuming equal amounts of current. Therefore, in this embodiment, the current through the heat generator 4 can be smaller than that in conventional heaters of similar design.

As explained, it is necessary to increase the temperature gradient (dT/dX) within the solid-phase monocrystal 6 at the solid-liquid interface in order to increase the maximum growing speed V_{max}. Accordingly, it would be preferable to reduce the heat output of the heat generator 4, because the monocrystal is heated by radiation from the heat generator 4.

In the apparatus according to the present invention, even if the heat output of the heat generator 4 is reduced in order to increase the temperature gradient (dT/dX), since the above-mentioned maximum difference in temperature between the surface 3a and the body of the melt 3 is small, it is possible to prevent the surface of the melt 3 from solidifying at the inner wall of the crucible 2. As a result, it is possible to markedly increase the growth rate by as much as 0.2 mm/min, for instance, over conventional systems. Additionally, it is possible to grow the monocrystal 6 continuously, thus increasing productivity and decreasing the cost of monocrystal manufacture.

The preferred embodiment of the method for producing or manufacture the silicon substrate according to the present invention employs the apparatus set forth above. It has been found in the present invention that the crystal growth rate exerts a great influence upon the generation of crystal defects, especially stacking faults. Therefore, in the present invention, the crystal growth rate is set to a value higher than 1.2 mm/min in order to obtain a silicon crystal body with an oxygen concentration of more than 1.8×10^{18} cm^{-3}. Silicon substrates are thus manufactured by wafering this silicon crystal body. Setting the silicon monocrystal growth rate higher that in the conventional systems prevents segregation of oxygen in succeeding heat treatments and so prevents the accompanying loss of grown silicon monocrystal quality. Therefore, it is possible to increase the oxygen concentration. In the present invention, oxygen concentration of 1.8×10^{18} cm^{-3} or more, can be achieved and thereby it is possible to obtain an enhanced I.G. effect.

The following discussion is directed to the finished silicon substrate produced by the preferred method according to the invention utilising the apparatus of Figures 1 and 2.

A silicon monocrystal body was drawn and grown by the CZ method. A wafer was cut from the monocrystal body. The surfaces of the wafer were mirror-polished, and then twice subjected to heat treatment at a temperature of 1100°C for 2 hours within a dry oxygen atmosphere. Thereafter, the wafer was etched to a depth of 13 μm by the so-called dry etching method ro reveal faults. In order to perform this test, various samples were obtained by varying the growth rate of the silicon monocrystal body in the CZ process. Also various samples were obtained at various oxygen concentrations. The density of stacking faults in these samples was measured. The results of these measurements are shown in Figure 3.

The results shown in Figure 3 indicate that essentially no stacking faults are formed if the silicon monocrystal growth rate is greater than or equal to 1.2 mm/min. Furthermore, it was also confirmed that no stacking faults are generated during treatment of the silicon wafer or silicon substrate, including surface polishing.

In addition, the changes in oxygen concentration due to heat treatment at 750°C were measured. Figure 4 shows the results of these measurements in the form of a curve relating oxygen concentration to heat treatment time. In the drawing, the curves 21 to 23 represent the relationship between oxygen concentration and heat treatment time at a crystal growth rate of greater than 1.2 mm/min. The initial oxygen concentrations for curves 21 to 26 were 1.644×10^{18} cm^{-3}, 1.667×10^{18} cm^{-3}, 1.709×10^{18} cm^{-3}, 1.866×10^{18} cm^{-3}, 2.019×10^{18} cm^{-3}, 2.019×10^{18} cm^{-3}, and 1.737×10^{18} cm^{-3}, respectively. Although the oxygen concentration eventually drops as oxygen is driven out of the silicon substrate or silicon monocrystal body by the heat treatment, it is clear that in the case of the high initial oxygen concentrations due tot he present invention, represented by the curves 24 to 26, the change is small even after a relatively long heat treatment and measurable oxygen loss occurs only after a very long time.

As will be appreciated from Figures 3 and 4, it is clear that high-speed crystal growth results in fewer faults.

In the next test, diodes were prepared by forming a $n^- - P$ junction on silicon substrates obtained by the present invention and the conventional method, and the p-n junction leak current was measured for each diode. In this case, a p-type region was formed on the n-type silicon substrate, and n^+ regions having an area of 2.4×10^{-12} cm piece/cm^2 were formed. The measurement was performed by applying a testing voltage of +5V to the n^+ region. The results of tests on silicon substrates formed from a silicon moncrystal body grown by the CZ method at a crystal growth rate greater than or equal to 1.2 mm/min and which have an oxygen concentration of 2.0×10^{18} cm^{-3}, are shown in Figure 5. On the other hand, Figure 6 shows the result of the tests performed on silicon substrates formed from a silicon monocrystal body grown by the conventional silicon monocrystal growing method at a crystal growth rate of 0.6 to 0.9 mm/min. In Figures 5 and 6, in the abscissa is the measured leak current and the ordinate is the number of samples exhibiting the indicated leak current. As can be understood by a comparison of Figures 5 and 6, the case of silicon substrates manufactured by the present invention, the lead current is reliably decreased to 10^{-11}A or less. This may be due to the pronounced I.G. effect produced by the high oxygen concentration.

It should be appreciated that the preferred method according to the present invention can provide a high-oxygen-concentration silicon crystal body. It is also possible to accurately select the oxygen concentration from a wide range by applying a crystal growth method in which a magnetic field is applied to a silicon melt in a quartz crucible and the crucible is rotated as necessary. An example of this crystal growth method employ-

ing a magnetic field will be explained with reference to Figure 7.

In the drawing, the entire apparatus is designated generally by the reference numeral 31. A quartz crucible 32 retains molten silicon from which a crystal is grown. The crucible 32 is rotated about its central axis at an adjustable rotational speed. A heating means 34 surrounds the crucible 32. The heating means 34 may be a cylindrical electric heater 35 similar to the heater 4 of the previous embodiment. A cylindrical heat insulating body, or a jacket 36 cooled by water, as necessary, is provided outwardly of the heating means. A direct current magnetic field generating means 37 made up of a permanent magnet or an electromagnet is located outwardly of the jacket 36. A silicon moncrystal seed is designated by the reference numeral 38 while a drawing chuck is shown at reference numeral 39. The drawing chuck 39 raises the silicon monocrystal seed 38 while rotating the seed about the rotational axis of the crucible.

The electrical power supply to the heating means 34 is dc current with 4% or less ripple or a 1 kHz or higher alternating or pulsating current. This type of current has been proven adequate to prevent unnecessary resonance between the heating means 34 and the magnetic field.

The monocrystalline silicon seed 38 is drawn away from the molten silicon surface at a predetermined speed so as to induce growth of a silicon monocrystal 40. In this case, varying the rotational speed of the crucible 32 in particular also changes the oxygen concentration in the finished crystal 40. This is due to the following reason. The molten silicon in the crucible has an effective viscosity enhanced by application of a magnetic field. Since the silicon is rotated relative to the crucible rotation, frictional contact between the molten silicon 3 and the inner walls of the crucible 32 results. Therefore, oxygen in the walls of the crucible 32, specifically of the quartz, is dissolved in the molten silicon 33. The oxygen concentration in the growing crystal 40 thus increases because the dissolved oxygen increases with increasing frictional contact, that is, with increasing rotational speed of the crucible relative to the molten silicon 33. Moreover, it has been confirmed that a higher oxygen concentration in the crystal can be achieved, if the rotational speed of the crucible is sufficiently high, when a magnetic field is applied than when no magnetic field is applied.

As described above, since it is possible to maintain a high oxygen concentration, the present invention has many advantages. For instance, the effects of thermal hysteresis as the crystal body is being pulled can be essentially eliminated. Since the oxygen concentration is high, an extremely high I.G. effect can be obtained in heat treatment. In addition, crystal faults in the substrate surface can be suppressed. Because of these advantages, in semiconductor elements formed on the silicon substrate many significant advantages are achieved, such as the lowering of the leak current, the improvement of breakdown voltage, increased uniformity of characteristics, the improvement of product yield, and so forth.

While the present invention has been disclosed in terms of the preferred embodiment in order to facilitate a better understanding of the invention, it should be appreciated that the invention can be embodied in various ways without departing from the scope of the invention. Therefore, the invention should be understood to include all possible embodiments and modifications to the shown embodiments which can be embodied without departing from the scope of the invention set out in the appended claims.

CLAIMS

1. A method of producing a silicon substrate containing a high concentration of oxygen for semiconductor devices comprising the steps of:

growing a silicon monocrystal from a silicon melt at a high rate of growth selected to prevent or substantially reduce loss of oxygen from the monocrystal during subsequent heat treatment during production of said semiconductor device; and

forming said silicon substrate from said silicon monocrystal.

2. A method as set forth in claim 1, wherein said growth rate of said silicon monocrystal is greater than or equal to 1.2 mm/min.

3. A method as set forth in claim 1, wherein said oxygen concentration in said silicon substrate is greater than or equal to $1.8 \times 10^{18} cm^{-3}$.

4. A method as set forth in claim 2, wherein said oxygen concentration in said silicon substrate is greater than or equal to $1.8 \times 10^{18} cm^{-3}$.

5. A method as set forth in any one of claims 1 to 4, wherein said growth rate of said silicon monocrystal is preferably in the range of approximately 1.5mm/min. to 2.1 mm/min.

6. A method as set forth in any one of the preceding claims, wherein said silicon monocrystal growth step comprises the steps of:

placing silicon in a crucible;

heating said silicon so as to maintain said silicon in a fluid state; and

gradually drawing said silicon monocrystal out of said silicon melt in said crucible.

7. A method as set forth in claim 6, wherein in said step of heating said silicon, the heat applied thereto is sufficient to prevent the surface of said silicon from solidifying.

8. A method as set forth in claim 7, wherein in said step of heating said silicon, more heat is applied to said surface of said silicon than to the remainder of said silicon melt.

9. A method as set forth in claims 6, 7 or 8, which further comprises the step of applying a magnetic field to said silicon so as to control the oxygen concentration.

10. A method as set forth in any one of claims 6 to 9 which further comprises the step of driving said crucible to rotate.

11. A method as set forth in claim 10, wherein the rotation speed of said crucible is controlled so as to adjust the oxygen concentration in said silicon substrate.

12. An apparatus for growing a silicon monocrystal containing a high concentration of oxygen as a source for silicon substrates for semiconductor devices, comprising:

a crucible for receiving a silicon;

a heater means for heating said silicon so as to maintain said silicon in a fluid state; and

a drawing means for drawing said silicon monocrystal from the silicon melt in said crucible at a high rate so as to prevent or substantially reduce loss of oxygen from said substrate during subsequent heat treatment in a process of fabricating said semiconductor devices.

13. An apparatus as set forth in claim 12, wherein said drawing rate of said silicon monocrystal is greater than or equal to 1.2 mm/min.

14. An apparatus as set forth in claim 13, wherein said oxygen concentration in said silicon substrate is greater than or equal to $1.8 \times 10^{18} cm^{-3}$.

15. An apparatus as set forth in claim 13 or 14, wherein the growth rate of said silicon monocrystal is preferably in the range of approximately 1.5mm/min. to 2.1 mm/min.

16. An apparatus as set forth in any one of claims 12 to 15, wherein said heating means applies sufficient heat to prevent the surface of said silicon melt from solidifying.

17. An apparatus as set forth in claim 16, wherein said heating means applies more heat to said surface of said silicon melt than to the remainder of said silicon melt.

18. An apparatus as set forth in any one of claims 12 to 17, which further comprises means for applying a magnetic field to said silicon melt so as to control the oxygen concentration.

19. An apparatus as set forth in any one of claims 12 to 18, which further comprises means for driving said crucible to rotate.

20. An apparatus as set forth in claim 19, wherein said crucible driving means drives said crucible at a variable speed allowing adjustment of said oxygen concentration in said silicon substrate.

21. A semiconductor device produced from a silicon substrate having an oxygen concentration greater than or equal to $1.8 \times 10^{18} cm^{-3}$ and having a leak current value less than 1×10^{-10}A.

22. A method for producing a silicon substrate with enhanced oxygen concentration comprising the steps of:

growing a silicon monocrystal from a silicon melt at an effective accelerated rate of growth to reduce the number of defects formed during subsequent heat treatment, to thus suppress separation of oxygen in the crystal body and to increase the oxygen in the crystal body, whereby leak current is reduced, said accelerated rate of growth being related to said enhanced oxygen concentration; and

forming said silicon substrate from said silicon monocrystal.

23. The method as set forth in claim 22, wherein said accelerated growth rate is at least 1.2mm/min. and the oxygen concentration is at least $1.8 \times 10^{18} cm^{-3}$.

24. The method as set forth in claim 23, wherein said accelerated growth rate is in a range of about 1.5 mm/min to about 2.1 mm/min.

25. The method as set forth in claim 22, 23 or 24 wherein said growing step includes the step of applying more heat to a surface of the silicon melt than to the remainder of said melt to prevent the surface of said silicon melt from solidifying.

26. A method as set forth in any one of claims 22 to 25, further including the step of applying a magnetic field to the silicon so as to control the oxygen concentration.

27. A method as set forth in any one of claims 22 to 26, further including the step of rotating a crucible contrary to said monocrystal.

28. A method as set forth in claim 27, further including the step of controlling the speed of rotation of said crucible to adjust the oxygen concentration in the silicon substrate.

29. A method of producing a silicon substrate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

30. Apparatus for growing a silicon monocrystal, such apparatus being constructed and arranged to operate substantially as hereinbefore described with reference to and as illustrated in the accompanying drawings.

31. A semiconductor device produced from a silicon substrate, the substrate having been made using the method of any one of claims 1 to 11 and 22 to 29 or the apparatus of any one of claims 12 to 21 and 30.

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